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(54) **MINIATURE ELECTRONIC SHOTGUN MICROPHONE**

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(30) **Foreign Application Priority Data**

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H04R 3/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04R 3/005*** (2013.01); *H04R 2201/403* (2013.01); *H04R 2430/25* (2013.01)

(58) **Field of Classification Search**
CPC H04R 3/005; H04R 2201/403; H04R 2430/25
USPC 381/92, 111, 122, 356
See application file for complete search history.

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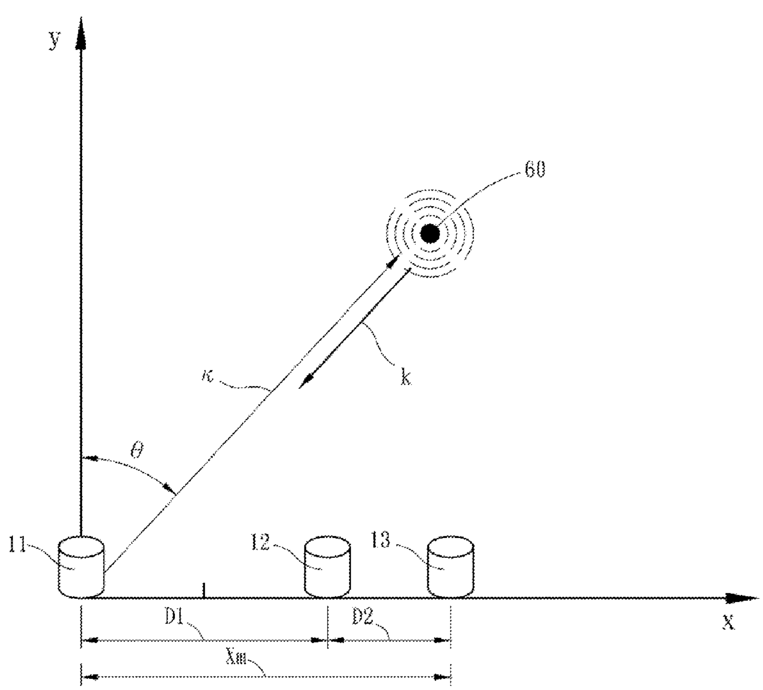
(57) **ABSTRACT**

A miniature electronic shotgun microphone, which is used to receive a sound source from a specified direction, comprises a pick-up member, an A/D (Analog/Digital) conversion unit, and a digital signal processor. The pick-up member includes a first pick-up unit, a second pick-up unit separated from the first pick-up unit by a first distance, and a third pick-up unit separated from the second pick-up unit by a second distance; the first distance is greater than the second distance. The first pick-up unit, the second pick-up unit and the third pick-up unit respectively receive the sound source and output an analog signal. The A/D conversion unit and the digital signal processor process the analog signals, and convert them into a directional digital acoustic signal. Thus, the directional digital acoustic signal has a maximum pick-up frequency. Thereby is decreased grating lobes and spatial aliasing.

8 Claims, 5 Drawing Sheets



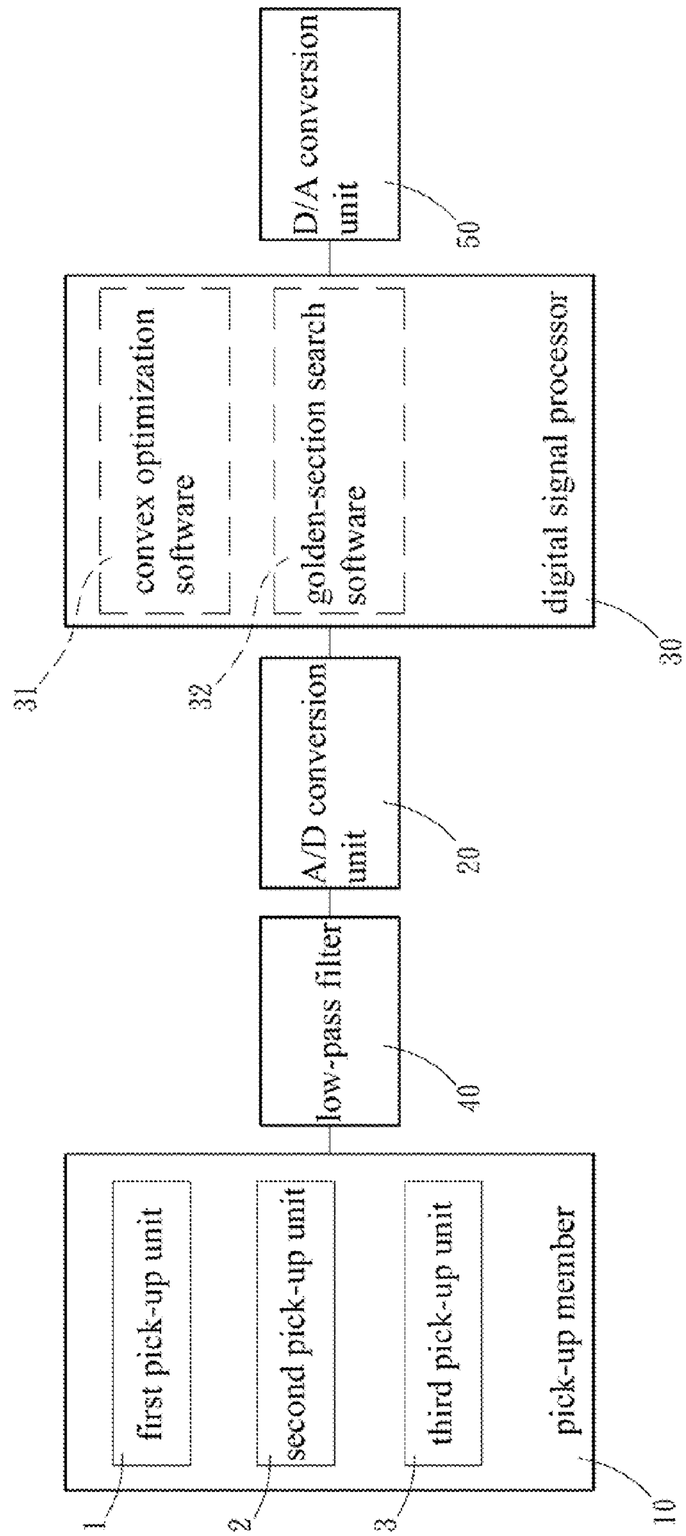

D/A conversion unit
50
convex optimization software
golden-section search software
digital signal processor
31
32
30
A/D conversion unit
20
low-pass filter
40
first pick-up unit
second pick-up unit
third pick-up unit
pick-up member
11
12
13
10

Fig. 1

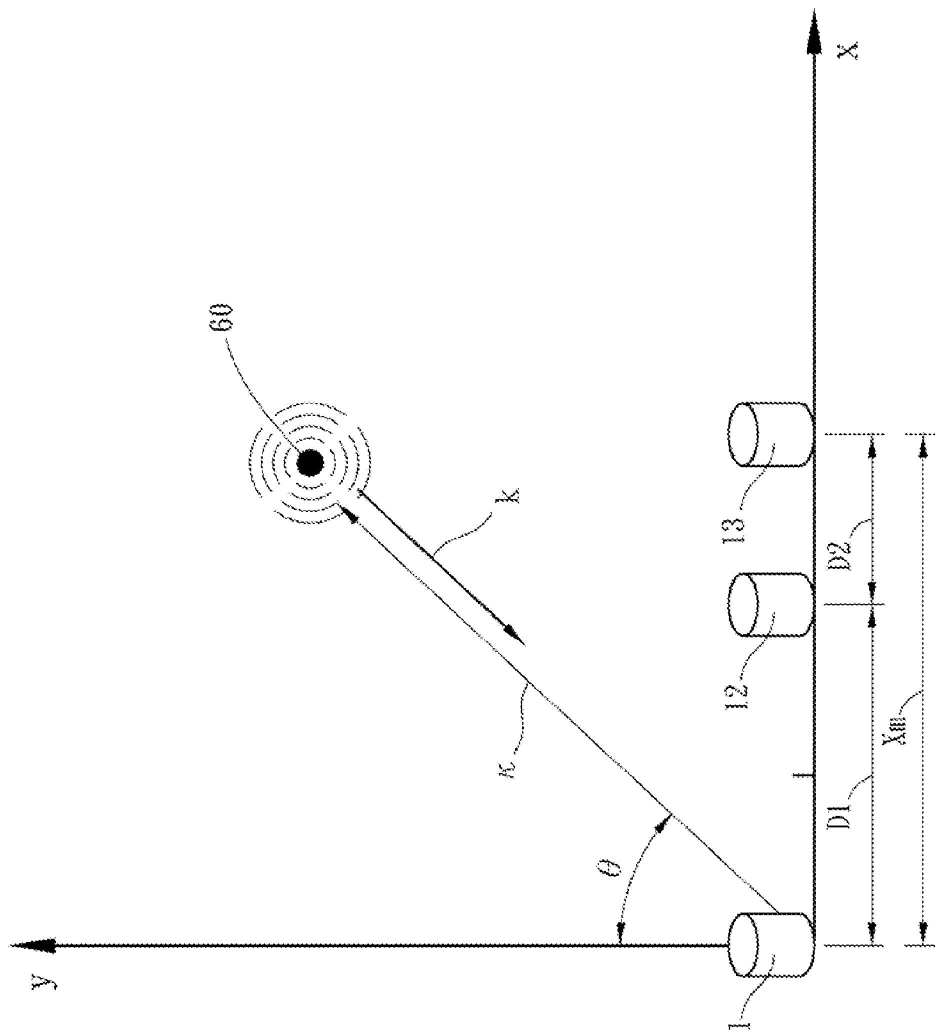


Fig. 2

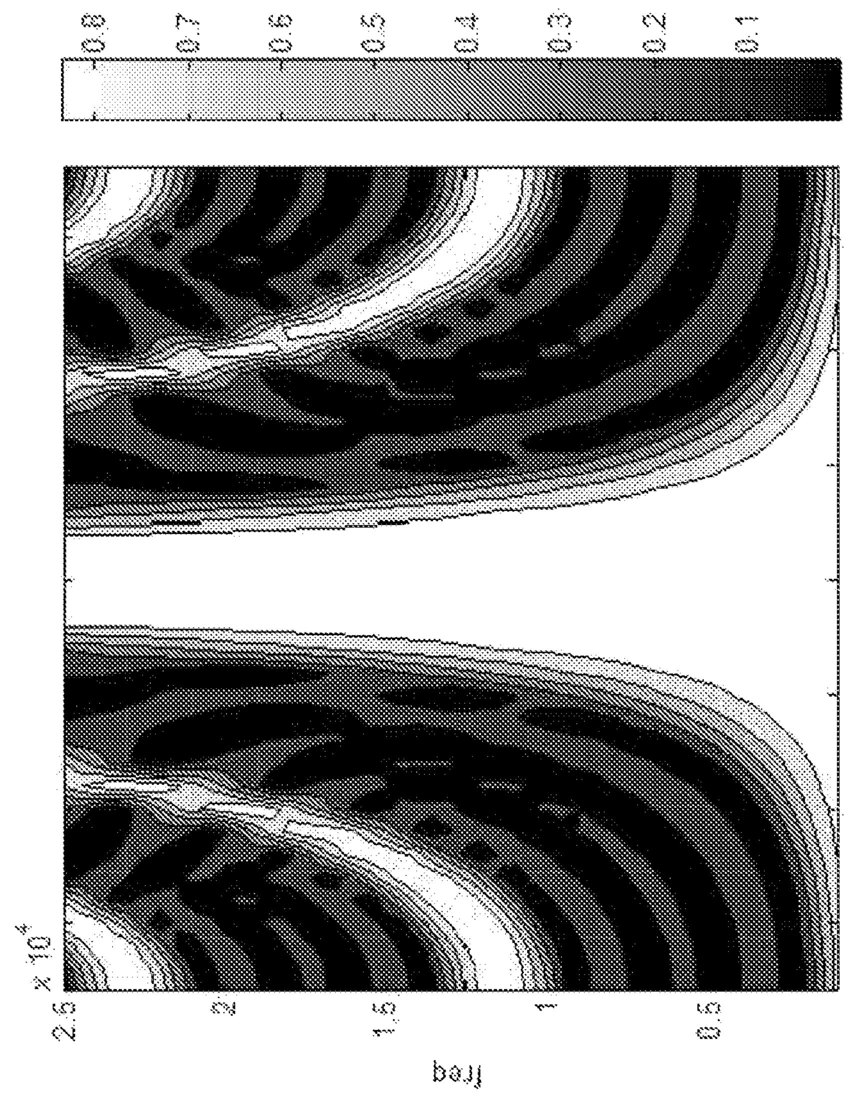


Fig. 3A (PRIOR ART)

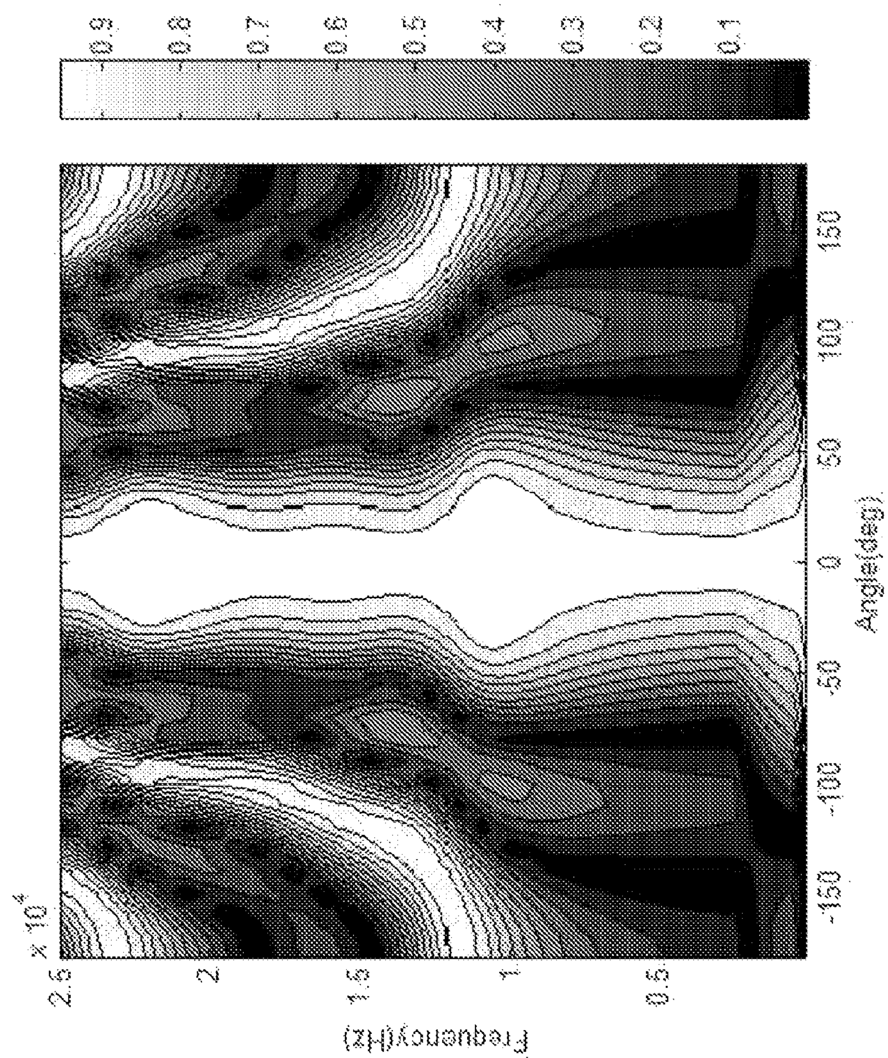
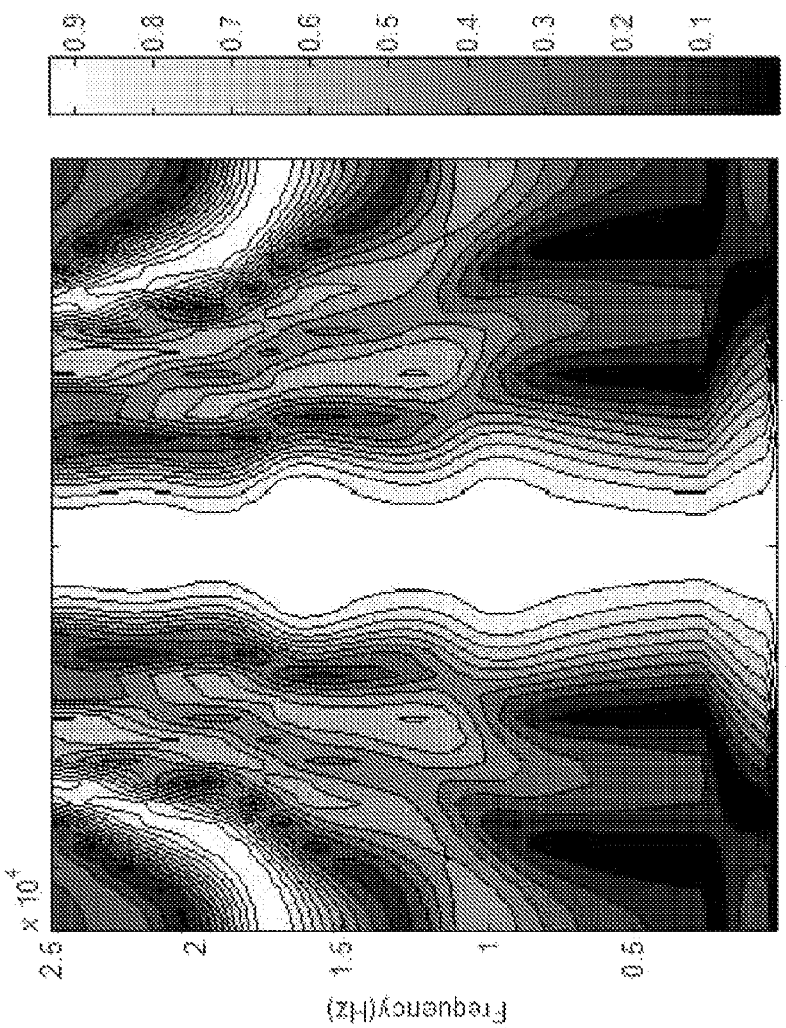


Fig. 3B (PRIOR ART)



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
x 10^4
2.5
2
1.5
1
0.5
Frequency(Hz)
-150
-100
-50
0
50
100
150
Angle(deg)

Fig. 3C

MINIATURE ELECTRONIC SHOTGUN MICROPHONE

FIELD OF THE INVENTION

The present invention relates to a microphone, particularly to a miniature electronic directional microphone.

BACKGROUND OF THE INVENTION

In a variety of occasions where sounds need picking up, such as a reporter's interview, a competition broadcast, an outdoor filming, there is noise coming from all directions. A common microphone would pick up many unnecessary noises in addition to the sounds intended to pick up. Therefore, a directional shotgun microphone is usually used in the above-mentioned occasions to pick up sounds coming from a specified direction and avoid noise interference from other directions.

A US publication No. 20110305359 disclosed a shotgun microphone, which comprises an acoustic tube, a connection member and a microphone unit, wherein the connection member connects the acoustic tube with the microphone unit. The conventional shotgun microphone uses the acoustic tube to achieve the pick-up directionality. The acoustic tube may be made of a porous material, whereby the acoustic tube can contract and extend to adjust the distance between the front end of the acoustic tube and the microphone unit, whereby is regulated the sound pick-up effect of the microphone unit.

The conventional shotgun microphone needs the acoustic tube to achieve the pick-up directionality. However, the acoustic tube is much larger than the microphone unit. Thus, the conventional shotgun microphone is bulky, hard to carry about, and inconvenient to use in many occasions.

SUMMARY OF THE INVENTION

The primary objective of the present invention is to solve the problem that the conventional shotgun microphone is bulky, hard to carry about and inconvenient to use.

To achieve the above-mentioned objective, the present invention proposes a miniature electronic shotgun microphone, which is used to pick up a sound source from a specified direction, and which comprises a pick-up member, an A/D (Analog/Digital) conversion unit, and a digital signal processor. The pick-up member includes a first pick-up unit, a second pick-up unit separated from the first pick-up unit by a first distance D**1**, and a third pick-up unit separated from the second pick-up unit by a second distance D**2**. The first, second, and third pick-up units respectively receive the sound source and output an analog signal. The A/D conversion unit electrically connects with the pick-up member, receives the analog signals, and converts the analog signals into a first digital signal, a second digital signal, and a third digital signal. The digital signal processor electrically connects with the A/D conversion unit and converts the first, second and third digital signals into a directional digital acoustic signal.

The first distance is greater than the second distance. Thus, the pick-up member has a maximum pick-up frequency greater than the frequency expressed by an Equation of

$$f = \frac{c}{D1 + D2},$$

and

wherein c is the sound speed.

Via the design of the first, second and third pick-up units and the first and second distances D**1** and D**2**, the miniature electronic shotgun microphone has a mini size and high directionality. Further, the pick-up member has the maximum pick-up frequency, whereby is increased the upper limit of the pick-up frequency and decreased the grating lobes and spatial aliasing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram schematically showing the architecture of a miniature electronic shotgun microphone according to one embodiment of the present invention;

FIG. **2** schematically shows the layout of the pick-up units of a miniature electronic shotgun microphone according to one embodiment of the present invention;

FIG. **3**A shows the simulation of the acoustic signal picked up by a conventional shotgun microphone with an acoustic tube;

FIG. **3**B shows the simulation of the acoustic signal picked up by a conventional equidistant array microphone; and

FIG. **3**C shows the simulation of the acoustic signal picked up by the miniature electronic shotgun microphone of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The technical contents of the present invention are described in detail in cooperation with drawings below.

Refer to FIG. **1** and FIG. **2**. FIG. **1** is a block diagram schematically showing the architecture of a miniature electronic shotgun microphone according to one embodiment of the present invention. FIG. **2** schematically shows the layout of the pick-up units of a miniature electronic shotgun microphone according to one embodiment of the present invention. The miniature electronic shotgun microphone of the present invention is used to receive a sound source **60** from a specified direction and comprises a pick-up member **10**, a low-pass filter **40**, an A/D (Analog/Digital) conversion unit **20**, and a digital signal processor **30**. The pick-up member **10** includes a first pick-up unit **11**, a second pick-up unit **12** and a third pick-up unit **13**, which are all fabricated with a microelectromechanical technology. The second pick-up unit **12** is separated from the first pick-up unit **11** by a first distance D**1**. The third pick-up unit **13** is separated from the second pick-up unit **12** by a second distance D**2**. The first distance D**1** is greater than the second distance D**2**. In one embodiment, the second pick-up unit **12** is arranged between the first pick-up unit **11** and the third pick-up unit **13**, and the three pick-up units are aligned collinearly. However, the present invention does not constrain that the three pick-up units must be aligned collinearly. In another embodiment, the three pick-up units are respectively arranged at the three apexes of a triangle. The first distance D**1** plus the second distance D**2** form a total pick-up length Xm. The first pick-up unit **11**, second pick-up unit **12** and third pick-up unit **13** respectively receive the sound source **60** and output an analog signal.

The low-pass filter **40** electrically connects with the pick-up member **10**, receives the analog signals output by the first pick-up unit **11**, second pick-up unit **12** and third pick-up unit **13**, filters out the high-frequency noise from the analog signals, and outputs the low-frequency portion of the analog signals. In one embodiment, the frequency allowed to pass the low-pass filter **40** depends on an effective bandwidth which is determined by the distance between the pick-up units (i.e. microphones). For example, the effective bandwidth may be decided by c/(2×D1) or c/(2×D2), wherein c is the sound speed, D1 is the first distance, and D2 is the second distance. Via the effective bandwidth is limited the bandwidth of the input sound source.

The A/D conversion unit **20** may either electrically connect with the pick-up member **10** through the low-pass filter **40** or directly electrically connect with the pick-up member **10**. The A/D conversion unit **20** receives the analog signals and converts the analog signals into a first digital signal, a second digital signal, and a third digital signal. Refer to FIG. **2**. In the coordinate space shown in FIG. **2**, the first digital signal may be expressed by Equation (1):

$$x_1(t)=s(t)e^{j(\omega_c t-k\cdot x_1)}=s(t)e^{j\left(\omega_c t-\frac{\omega_c}{c}k\cdot x_1\right)},\ x_1=(0,0); \tag{1}$$

the second digital signal may be expressed by Equation (2):

$$x_2(t)=s(t)e^{j(\omega_c t-k\cdot x_2)}=s(t)e^{j\left(\omega_c t-\frac{\omega_c}{c}k\cdot x_2\right)},\ x_2=(D1,0); \tag{2}$$

the third digital signal may be expressed by Equation (3):

$$x_3(t)=s(t)e^{j(\omega_c t-k\cdot x_3)}=s(t)e^{j\left(\omega_c t-\frac{\omega_c}{c}k\cdot x_3\right)},\ x_3=(D1+D2,0)=(Xm,0). \tag{3}$$

In the above-mentioned equations, s(t) is the baseband signal, ω_c is the center frequency, k is the wave vector=$\omega_c\kappa/c$, κ=(sin θ,cos θ), and c is the sound speed.

The digital signal processor **30** electrically connects with the A/D conversion unit **20** and receives the first, second and third digital signals, which are expressed by Equations (4) and (5):

$$x(t)=\begin{bmatrix}x_1(L)\\ \vdots\\ x_3(t)\end{bmatrix}=\begin{bmatrix}e^{j\omega_c\frac{\kappa\cdot x_1}{c}}\\ \vdots\\ c^{j\omega_c\frac{\kappa\cdot x_3}{c}}\end{bmatrix}s(t)e^{j\omega_c t}+\begin{bmatrix}n_1(L)\\ \vdots\\ n_3(t)\end{bmatrix}=a(\kappa)r(t)+n(t) \tag{4}$$

$$a(\kappa)=\left[e^{j\omega_c\frac{\kappa\cdot x_1}{c}}\ \ldots\ e^{j\omega_c\frac{\kappa\cdot x_3}{c}}\right]^T,\ r(t)=s(t)e^{j\omega_c t} \tag{5}$$

wherein $n_1(t)$–$n_3(t)$ are respectively the uncorrected noise signals of the pick-up units, a(κ) is the directional vector, and n(t) is the noise signal.

The digital signal processor **30** includes convex optimization software **31**. The convex optimization software **31** is used to perform convex optimization process for Equation (5) to sets weights to the first, second and third digital signals to form a directional digital acoustic signal expressed by Equation (6):

$$h(\omega,\kappa)=w^H a(\kappa) \tag{6}$$

wherein w^H is the set weight.

Please refer to a paper "Convex Optimization" by S. Boyd and L. Vandenberghe (Cambridge University Press, New York, 2004). The method proposed in this paper is also included in the specification and regarded as a prior art used by the present invention.

In one embodiment, the digital signal processor **30** also includes golden-section search software **32**. The digital signal processor **30** uses the golden-section search software **32** to set the values of the first and second distances D1 and D2 in a golden-section search way so as to optimize the directional digital acoustic signal. In one embodiment, the golden-section search is implemented with a calculation factor—Equation (7) and a target function—Equation (8):

$$E(\omega,x)=\frac{|w^H a|\ \text{sidelobe}}{|w^H a|\ \text{mainlobe}} \tag{7}$$

$$Q(x)=\frac{1}{I}\sum_{i=1}^{I}E(\omega_i,x) \tag{8}$$

wherein I is the section number of the set frequency range, ω_i is the ith frequency point, and x a set variable that may be the first distance D1.

Please refer to a paper "Algorithms for Minimization without Derivatives" by R. P. Brent (Prentice-Hall, Englewood Cliffs, N.J., p. 48-75 (1973).-GSS-PI). The method proposed in this paper is also included in the specification and regarded as a prior art used by the present invention.

In one embodiment, the miniature electronic shotgun microphone of the present invention further comprises a D/A (Digital/Analog) conversion unit **50**. The D/A conversion unit **50** electrically connects with the digital signal processor **30**, receives the directional digital acoustic signal from the digital signal processor **30**, and converts the directional digital acoustic signal into a directional analog acoustic signal for outputting.

Refer to FIGS. **3A-3C**. FIG. **3A** shows the simulation of the acoustic signal picked up by a conventional shotgun microphone with an acoustic tube. The acoustic tube of the conventional shotgun microphone has a total length of 6 cm, and the spacing between the pores of the acoustic tube is 1.5 cm. It is observed in FIG. **3A** that grating lobes and spatial aliasing occur when the frequency of the sound source **60** is higher than 11000 Hz. Thus is affected the directionality of the conventional shotgun microphone. FIG. **3B** shows the simulation of the acoustic signal picked up by a conventional equidistant array microphone. The conventional equidistant array microphone has three microphones; the adjacent microphones are separated by a spacing of 1.5 cm, thus the total spacing of the array microphone is 3 cm. The picked acoustic signal is processed with the convex optimization method and shown in FIG. **3B**. It is observed in FIG. **3B** that the directionality of the picked acoustic signal is superior to that of the abovementioned shotgun microphone at lower frequencies. However, grating lobes and spatial aliasing still occur in FIG. **3B** when the frequency of the sound source **60** is higher than 11000 Hz. FIG. **3C** shows the simulation of the acoustic signal picked up by the miniature electronic shotgun microphone of the present invention. The miniature electronic shotgun microphone of the present invention has a total pick-up length Xm of 3 cm; the golden-section search method sets the first distance D1 and the second distance D2 to be respectively 2 cm and 1 cm. The picked acoustic signal is processed with the convex optimization method to form the directional digital acoustic signal shown in FIG. **3C**. It is observed in FIG. **3C** that the width of the directional digital acoustic signal is more concentrated along the main axis (at an angle of 0 degree) than that of the acoustic signal picked up by the equidistant array microphone. Further, grating lobes do not occur until the frequency of the sound source **60** reaches as high as 17000 Hz. Therefore, the present invention can effectively reduce grating lobes and spatial aliasing and has the maximum pick-up frequency.

Suppose that the conventional equidistant array microphone has three microphones, and respectively define the spacing between the first and second microphones and the spacing between the second and third microphones to be d_1 and d_2. Thus, the maximum pick-up frequency f can be worked out according to Equation (9):

$$f = \frac{c}{2d} = \frac{c}{d_1 + d_2} \tag{9}$$

wherein c is the sound speed and d is the spacing between microphones.

In the example of FIG. **3**B, the equidistant array microphone has a pick-up frequency of:

$$f = \frac{c}{d_1 + d_2} = \frac{340}{0.015 + 0.015} = 11333(\text{Hz})$$

Therefore, it is observed in FIG. **3**B that grating lobes and spatial aliasing occur when the frequency of the sound source **60** exceeds 11000 Hz. Suppose that the number of the pick-up units of the present invention is equal to the number of the microphones of the above-mentioned equidistant array microphone and that the total pick-up length Xm of the present invention is also equal to the total length of the spacing of the above-mentioned equidistant array microphone. Thus, D**1**+D**2** is equal to d_1+d_2. It is observed in FIG. **3**C that grating lobes do not occur until the frequency of the sound source **60** exceeds 17000 Hz. Therefore, the pick-up member **10** of the present invention has a maximum pick-up frequency higher than the above-mentioned pick-up frequency f.

Via the design of the first, second and third pick-up units and the design that the first distance is greater than the second distance, the miniature electronic shotgun microphone of the present invention has greater directionality pick-up effect. Further, the miniature electronic shotgun microphone of the present invention has a maximum pick-up frequency to increase the upper limit of the pick-up frequency and decrease grating lobes and spatial aliasing when the total pick-up length and the number of the pick-up units are identical to those of the conventional equidistant array microphone. The present invention can be fabricated with a microelectromechanical technology, whereby the present invention not only has higher directionality but also has miniature size, in comparison with the conventional shotgun microphone having an acoustic tube, and whereby the present invention is easy to carry about and applicable to various mobile electronics.

The embodiments described above are only to exemplify the present invention but not to limit the scope of the present invention. Any equivalent modification or variation according to the spirit of the present invention is to be also included within the scope of the present invention.

What is claimed is:

1. A miniature electronic shotgun microphone, which is used to receive a sound source from a specified direction, comprising:

a pick-up member including a first pick-up unit, a second pick-up unit separated from the first pick-up unit by a first distance D**1**, and a third pick-up unit separated from the second pick-up unit by a second distance D**2**, wherein the first pick-up unit, the second pick-up unit and the third pick-up unit receive the sound source and output analog signals;

an analog/digital (A/D) conversion unit electrically connecting with the pick-up member, receiving the analog signals, and converting the analog signals into a first digital signal, a second digital signal, and a third digital signal;

a low-pass filter, which is arranged between the pick-up member and the A/D conversion unit and electrically connected with the pick-up member and the A/D conversion unit; and

a digital signal processor electrically connecting with the A/D conversion unit, receiving the first digital signal, the second digital signal and the third digital signal, and converting the first digital signal, the second digital signal and the third digital signal into a directional digital acoustic signal,

wherein the first distance is greater than the second distance, and

wherein the pick-up member has a maximum pick-up frequency higher than a pick-up frequency f expressed by an Equation of

$$f = \frac{c}{D1 + D2},$$

and

wherein c is a sound speed, wherein the digital signal processor includes convex optimization software, which sets weights of the first digital signal, the second digital signal and the third digital signal.

2. The miniature electronic shotgun microphone according to claim **1** further comprising a digital/analog (D/A) conversion unit, which electrically connects with the digital signal processor to receive the directional digital acoustic signal and convert the directional digital acoustic signal into a directional analog acoustic signal for outputting.

3. The miniature electronic shotgun microphone according to claim **1**, wherein the first pick-up unit, the second pick-up unit and the third pick-up unit are aligned collinearly.

4. The miniature electronic shotgun microphone according to claim **1**, wherein the first pick-up unit, the second pick-up unit and the third pick-up unit are aligned non-collinearly.

5. A miniature electronic shotgun microphone, which is used to receive a sound source from a specified direction, comprising:

a pick-up member including a first pick-up unit, a second pick-up unit separated from the first pick-up unit by a first distance D**1**, and a third pick-up unit separated from the second pick-up unit by a second distance D**2**, wherein the first pick-up unit, the second pick-up unit and the third pick-up unit receive the sound source and output analog signals;

an analog/digital (A/D) conversion unit electrically connecting with the pick-up member, receiving the analog signals, and converting the analog signal into a first digital signal, a second digital signal, and a third digital signal; and

a digital signal processor electrically connecting with the A/D conversion unit, receiving the first digital signal, the second digital signal and the third digital signal, and converting the first digital signal, the second digital signal and the third digital signal into a directional digital acoustic signal,

wherein the first distance is greater than the second distance, and wherein the pick-up member has a maximum pick-up frequency higher than a pick-up frequency f expressed by an Equation of

$$f = \frac{c}{D1 + D2},$$

and

wherein c is a sound speed;

wherein the digital signal processor includes convex optimization software, which sets weights of the first digital signal, the second digital signal and the third digital signal; and

wherein the digital signal processor includes golden-section search software,

which sets values of the first distance and second distance.

6. The miniature electronic shotgun microphone according to claim **5** further comprising a digital/analog (D/A) conversion unit, which electrically connects with the digital signal processor to receive the directional digital acoustic signal and convert the directional digital acoustic signal into a directional analog acoustic signal for outputting.

7. The miniature electronic shotgun microphone according to claim **5**, wherein the first pick-up unit, the second pick-up unit and the third pick-up unit are aligned collinearly.

8. The miniature electronic shotgun microphone according to claim **5**, wherein the first pick-up unit, the second pick-up unit and the third pick-up unit are aligned non-collinearly.

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